Noise figure

Noise figure (NF) and **noise factor** (*F*) are figures of merit that indicate degradation of the signal-to-noise ratio (SNR) that is caused by components in a signal chain. These figures of merit are used to evaluate the performance of an amplifier or a radio receiver, with lower values indicating better performance.

The noise factor is defined as the ratio of the output noise power of a device to the portion thereof attributable to thermal noise in the input termination at standard noise temperature T_0 (usually 290 K). The noise factor is thus the ratio of actual output noise to that which would remain if the device itself did not introduce noise, or the ratio of input SNR to output SNR.

The noise *factor* and noise *figure* are related, with the former being a unitless ratio and the latter being the same ratio but expressed in units of decibels (dB).[1]

General

The noise figure is the difference in decibels (dB) between the noise output of the actual receiver to the noise output of an "ideal" receiver with the same overall gain and bandwidth when the receivers are connected to matched sources at the standard noise temperature T_0 (usually 290 K). The noise power from a simple load is equal to kTB, where k is the Boltzmann constant, T is the absolute temperature of the load (for example a resistor), and B is the measurement bandwidth.

This makes the noise figure a useful figure of merit for terrestrial systems, where the antenna effective temperature is usually near the standard 290 K. In this case, one receiver with a noise

figure, say 2 dB better than another, will have an output signal to noise ratio that is about 2 dB better than the other. However, in the case of satellite communications systems, where the receiver antenna is pointed out into cold space, the antenna effective temperature is often colder than 290 K.[2] In these cases a 2 dB improvement in receiver noise figure will result in more than a 2 dB improvement in the output signal to noise ratio. For this reason, the related figure of *effective noise temperature* is therefore often used instead of the noise figure for characterizing satellite-communication receivers and low-noise amplifiers.

In heterodyne systems, output noise power includes spurious contributions from image-frequency transformation, but the portion attributable to thermal noise in the input termination at standard noise temperature includes only that which appears in the output via the principal frequency transformation of the system and excludes that which appears via the image frequency transformation.

Definition

The **noise factor** F of a system is defined as[3]

$$F = \frac{\mathrm{SNR_i}}{\mathrm{SNR_o}}$$

where $\mathrm{SNR_i}$ and $\mathrm{SNR_o}$ are the input and output signal-to-noise ratios respectively. The SNR quantities are unitless power ratios. The noise figure NF is defined as the noise factor in units of decibels (dB):

$$\mathrm{NF} = 10\log_{10}(F) = 10\log_{10}\left(\frac{\mathrm{SNR_i}}{\mathrm{SNR_o}}\right) = \mathrm{SNR_{i,\,dB}} - \mathrm{SNR_{o,\,dB}}$$

where $\mathrm{SNR_{i,\,dB}}$ and $\mathrm{SNR_{o,\,dB}}$ are in units of (dB). These formulae are only valid when the input termination is at standard noise temperature T_0 = 290 K, although in practice small differences in temperature do not significantly affect the values.

The noise factor of a device is related to its noise temperature T_e:[4]

$$F = 1 + \frac{T_\mathrm{e}}{T_0}.$$

Attenuators have a noise factor F equal to their attenuation ratio L when their physical temperature equals T_0. More generally, for an attenuator at a physical temperature T, the noise temperature is $T_e = (L - 1)T$, giving a noise factor

$$F = 1 + \frac{(L-1)T}{T_0}.$$

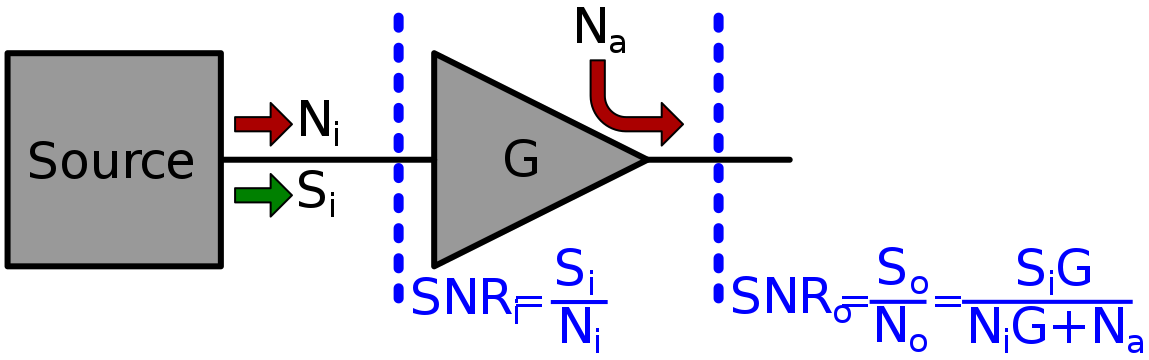
Noise factor of cascaded devices

If several devices are cascaded, the total noise factor can be found with Friis' formula:[5]

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3} + \cdots + \frac{F_n - 1}{G_1 G_2 G_3 \cdots G_{n-1}},$$

where F_n is the noise factor for the n-th device, and G_n is the power gain (linear, not in dB) of the n-th device. The first amplifier in a chain usually has the most significant effect on the total noise figure because the noise figures of the following stages are reduced by stage gains. Consequently, the first amplifier usually has a low noise figure, and the noise figure requirements of subsequent stages is usually more relaxed.

Noise factor as a function of additional noise



The source outputs a signal of power S_i and noise of power N_i. Both signal and noise get amplified. However, in addition to the amplified noise from the source, the amplifier adds additional noise to its output denoted N_a. Therefore, the SNR at the amplifier's output is lower than at its input.

The noise factor may be expressed as a function of the additional output referred noise power N_a and the power gain G of an amplifier.

$$F = 1 + \frac{N_a}{N_i G}$$

Derivation

From the definition of noise factor[3]

$$F = \frac{\mathrm{SNR_i}}{\mathrm{SNR_o}} = \frac{\frac{S_i}{N_i}}{\frac{S_o}{N_o}},$$

and assuming a system which has a noisy single stage amplifier. The signal to noise ratio of this amplifier would include its own output referred noise N_a, the amplified signal $S_i G$ and the amplified input noise $N_i G$,

$$\frac{S_o}{N_o} = \frac{S_i G}{N_a + N_i G}$$

Substituting the output SNR to the noise factor definition,[6]

$$F = \frac{\frac{S_i}{N_i}}{\frac{S_i G}{N_a + N_i G}} = \frac{N_a + N_i G}{N_i G} = 1 + \frac{N_a}{N_i G}$$

In cascaded systems N_i does not refer to the output noise of the previous component. An input termination at the standard noise temperature is still assumed for the individual component. This means that the additional noise power added by each component is independent of the other components.

See also

- Noise
- Noise (electronic)
- Noise figure meter
- Noise level

- Thermal noise
- Signal-to-noise ratio
- Y-factor

References

1. *"Noise temperature, Noise Figure and Noise Factor" (http://www.satsig.net/noise.htm)* .
2. *Agilent 2010, p. 7*
3. *Agilent 2010, p. 5.*
4. *Agilent 2010, p. 7 with some rearrangement from* $T_e = T_0(F - 1)$.
5. *Agilent 2010, p. 8.*
6. *Aspen Core. Derivation of noise figure equations (DOCX) (https://m.eet.com/media/1163845/4065-download_a_word_document.doc) , pp. 3–4*

- Keysight, *Fundamentals of RF and Microwave Noise Figure Measurements* (http://literature.cdn.keysight.com/litweb/pdf/5952-8255E.pdf) (PDF), Application Note, 57-1, Published September 01, 2019.

External links

- Noise Figure Calculator (http://www.emtalk.com/tools/noise-figure-calculator.php) 2- to 30-Stage Cascade
- Noise Figure and Y Factor Method Basics and Tutorial (https://web.archive.org/web/20120316061413/http://testrf.com/2011/noise-figure-uncertainties-y-factor-method/)
- Mobile phone noise figure (https://toyproblem.github.io/phone-noise-figure/)

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